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The quality inspection method for master-matrices of security holograms

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Abstract

Security holograms are perspective for document and product authenticity protection due to difficulties of such a protection mark falsification. The quality of security holograms and master-matrices significantly depends on perfection of diffraction grating. We represent the quality inspection method of security hologram based on indirect measurements of diffraction grating parameters. The theoretical results of our method application for quality inspection are shown in this paper.

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Keywords: security holograms; master-matrix; quality inspection; diffraction grating.

1. Introduction

Application of security holograms (SH) for document, product or authority protection is widely used around the globe as shown by Zlokazov E.Yu., Starikov R.S., Odinokov S.B. et al (2013). High security level of SH is achieved by unique design of holographic images that combine complex 3D scenes with such a security features as concealed images and microtext, kinetic effects, hidden laser readable images etc. Mass production of SH utilizes widespread technique of hot foil or lavsan paper stamping with the use of nickel master-matrix. The relief of master-matrix represents pixel structure of diffraction patterns with the grating period of up to 0.8μm. Riffling of such a structure requires application of specialized and technologically advanced lithography equipment. Thus, the forgery of SH is next to impossible.

The quality of mass produced SH is basically depends on ideality of master-matrix that is used in pressing

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equipment. Defects and relief distortions caused by elastic deformation during copying, excessive ware and mechanical damage of master-matrix lead to degradation of holographic image and loss of its unique security features. Thus the problem of prior master-matrix quality inspection causes a special interest of SH mass manufacturers.

The purpose of this work is to develop a method to carry out an objective assessment about the quality of the master-matrix of security holograms.

Currently, there is no consensus for approaches to assessing the quality of security holograms. Assuming that quality inspection carried out on selected areas of security holograms design, the inspection can be reduced to the measurement of the following parameters of the diffraction grating:

- spatial frequency ν;
- grating depth d;
- number of periods in the grating N;
- grating orientation φ.

Due to the period of gratings has a value of about 1 μm, the method based on direct measurement of the diffraction gratings parameters can be used. Such parameters as profile shape, spatial frequency and grating depth can be directly measured with the microscope. However, the disadvantage of this method is labor intensity and duration of the grating parameters measurement.

An alternative to this method is an indirect method of measurement. It is known that:

1) For a given value of wavelength the intensity distribution I over the diffraction orders of the phase grating depends on the grating depth d.

2) For a given value of the incidence wavefront angle, the value of diffraction orders angles depends on the value of the spatial frequency.

3) The orientation of the plane in which there are positive and negative diffraction orders depends on the orientation diffraction grating φ.

4) Angular size of the diffraction orders (or angular selectivity) depends on the number of periods in the grating N.

Therefore, with measuring the value of the intensity distribution, the orientation of the plane and the angular size of the diffraction orders we can uniquely estimate the parameters of the grating.

2. Diffraction in the reflective phase grating

Known mathematical expressions describing within the scalar theory of diffraction process in the reflective phase grating as described by M. Born, E. Wolf (1973) and A.M. Khorokhorov, A.M. Klishyuk et al (2005). Fig. 1 explains the occurrence of phase shift in the diffraction on the sinusoidal reflective grating.

The equation of the phase grating surface can be represented as

$$z = A \cdot \left(1 - \cos \frac{2\pi x}{T}\right) = 2A \sin^2 \frac{\pi x}{T}, \qquad (1)$$

where A and T – the amplitude and the period of the sinusoidal profile, respectively.

In accordance with the Huygens-Fresnel principle, each point of the incident wavefront, becoming a source of secondary waves, creates in the observation direction the wave whose amplitude is equal to

$$U = U_0 \int_0^{NT} e^{ik\Delta_x} dx, \qquad (2)$$

where U_0 – constant, proportional to the amplitude of the incident wave, $k = 2\pi/\lambda$ – wavenumber, Δ_x – optical path difference between the beams 1 and 2 diffracted from the grating, N – number of periods in the grating.

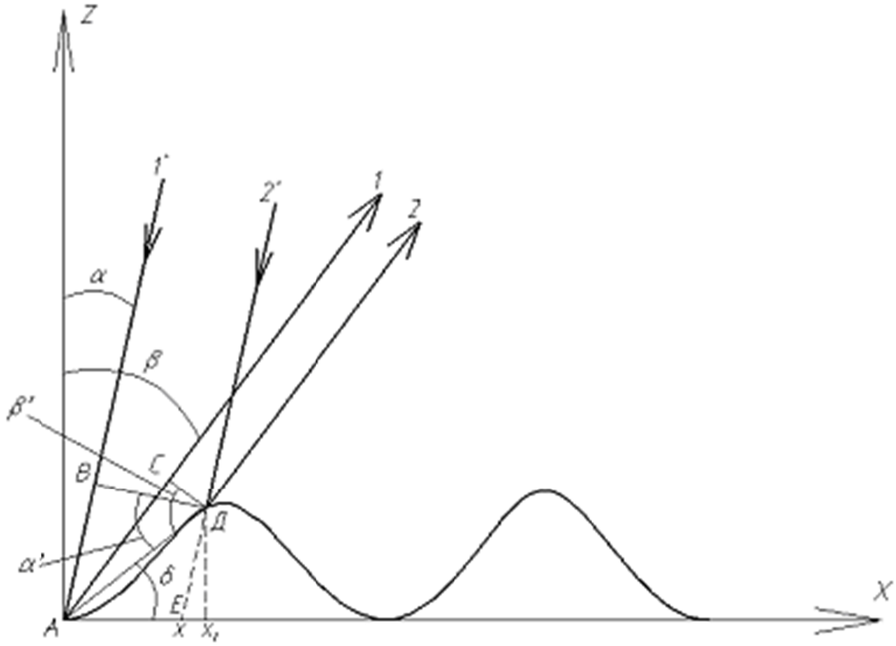

Fig. 1. Diffraction by the phase grating

Considering the profile of the grating is periodical, we can write

$$\Delta_x = \Delta_{1x} + j\Delta_0 , \quad (3)$$

where Δ_{1x} – value of the optical path difference within the one period, Δ_0 – optical path difference for the profile points spaced along the X axis by the amount of period T. Then (2) takes the form

$$U = U_0 \cdot \int_0^T e^{ik\Delta_{1x}} dx \cdot \sum_{j=0}^{N} e^{ikj\Delta_0} \quad (4)$$

Equation (4) can be written as

$$U = U_0 \cdot U_1 \cdot U_2 , \quad (5)$$

where

$$U_1 = \int_0^T e^{ik\Delta_{1x}} dx , \quad (6)$$

$$U_2 = \sum_{j=0}^{N} e^{ikj\Delta_0} , \quad (7)$$

where

$$\Delta_0 = T(\sin\alpha + \sin\beta) \quad (8)$$

Then the intensity distribution in the diffraction distribution can be represented as

$$I = I_0 \cdot I_1 \cdot I_2 , \quad (9)$$

where

$$I_1 = \left|U_1\right|^2 , \quad (10)$$

$$I_2 = \left|U_2\right|^2 = \frac{\sin^2\left(\pi \dfrac{N\Delta_0}{\lambda}\right)}{\sin^2\left(\dfrac{\pi\Delta_0}{\lambda}\right)}, \tag{11}$$

$$I_0 = \left|U_0\right|^2 \text{ – intensity of the incident wave.} \tag{12}$$

3. The results of calculations

Using a mathematical model based on the approximation of the scalar diffraction theory, the calculations and the relationship between intensity distribution I and grating depth d are obtained. The obtained relationships are represented in graphs.

The Fig. 2 illustrates the distribution of the intensity component I_2 in the orders of diffraction within number of periods in the grating of 10 and an emission wavelength of 600 nm.

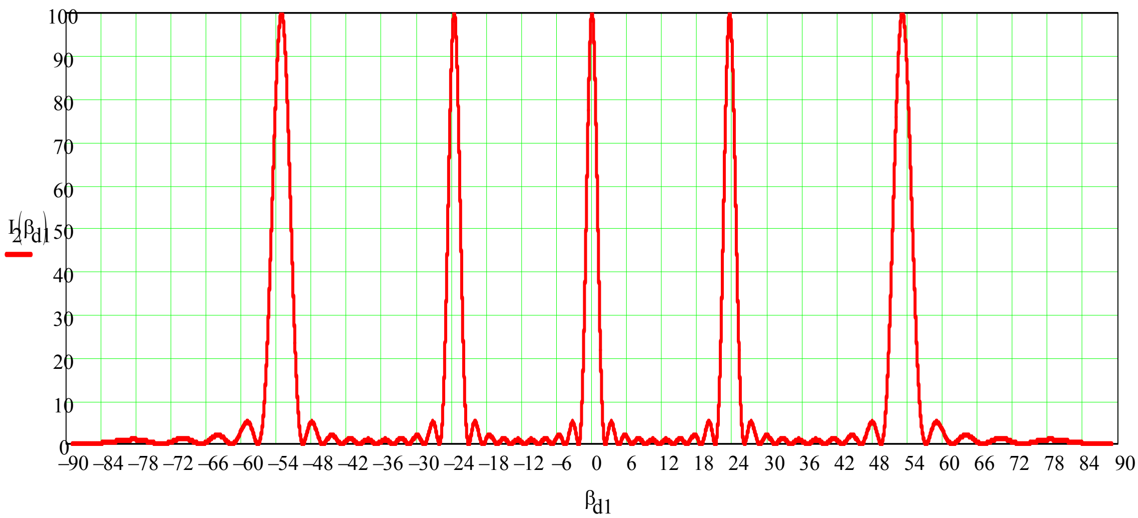

Fig. 2. Distribution of the intensity component I_2 in the orders of diffraction

The Fig. 3 and the Fig. 4 illustrate the graphs of the relationship between intensity distribution I in the first order of diffraction and grating depth d for normal incidence of radiation. The relationships are represented for incident radiation with wavelengths of 400, 500, 600, 650 and 700 nm and within grating period $T = 1{,}5$ um and $T = 1$ um.

The Fig. 5 illustrates the graphs of the relationship between the angular selectivity of the first-order diffraction $\Delta\beta$ and the number of periods in the grating N for incident radiation angle α of 0, 20º, 40º and 70º. This graph shows the angular selectivity decreases with increasing the number of periods in the grating.

The Fig. 6 illustrates the graphs of the relationship between the angular selectivity of the first-order diffraction $\Delta\beta$ and the incident radiation angle α for number of periods in the grating N of 10, 40, 70 and 100. This graph shows the angular selectivity decreases with increasing the incident radiation angle α up to 40º, and then the angular size increases.

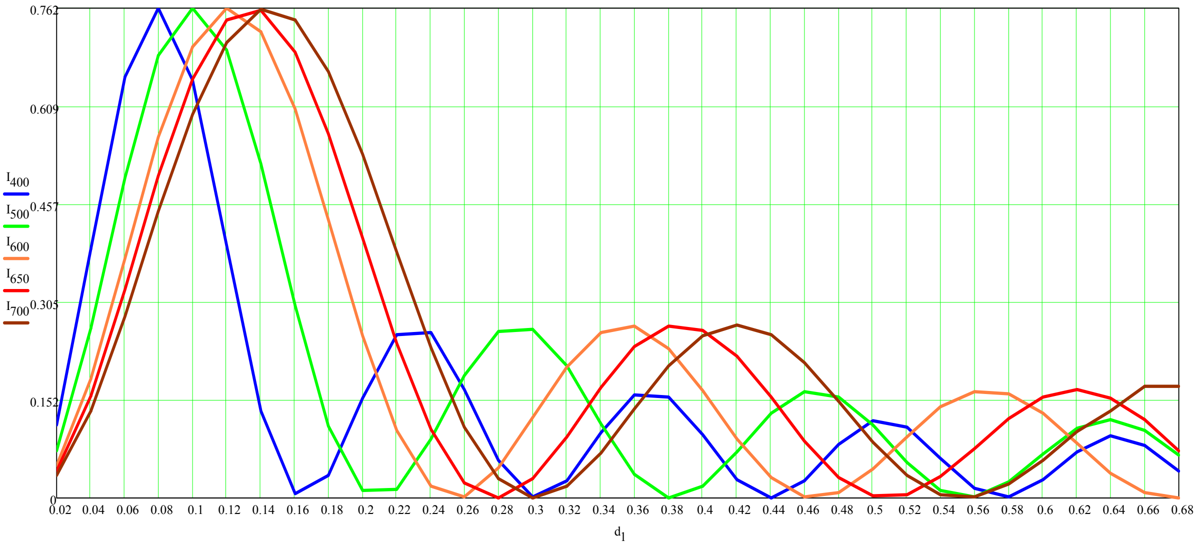

Fig. 3. The relationship between intensity distribution I and grating depth d within grating period $T = 1{,}5$ um

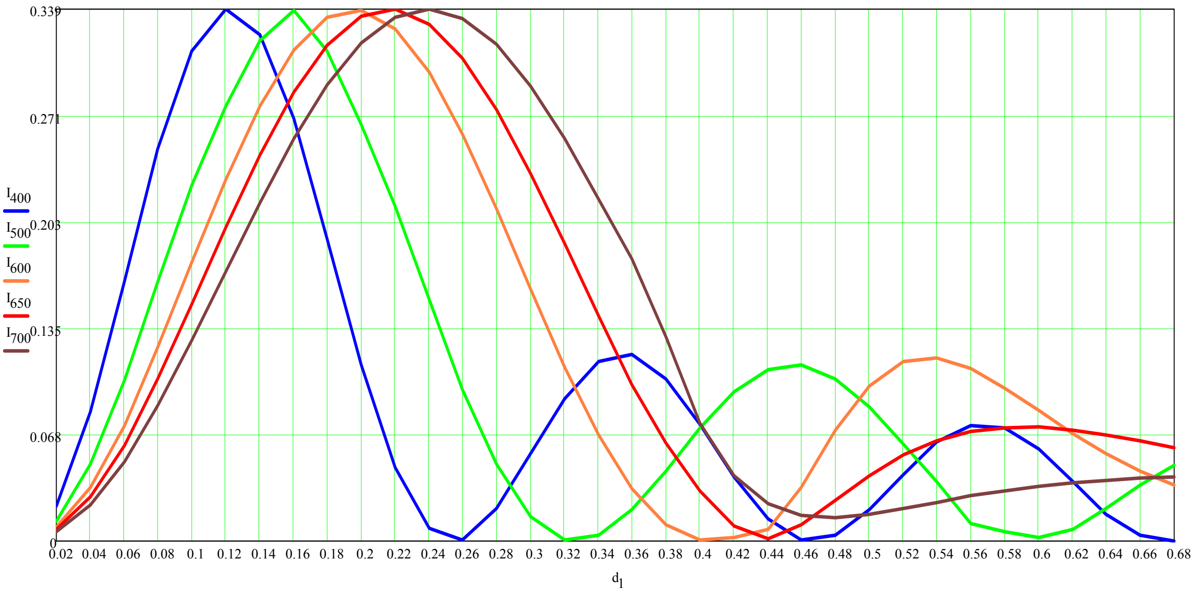

Fig. 4. The relationship between intensity distribution I and grating depth d within grating period $T = 1$ um

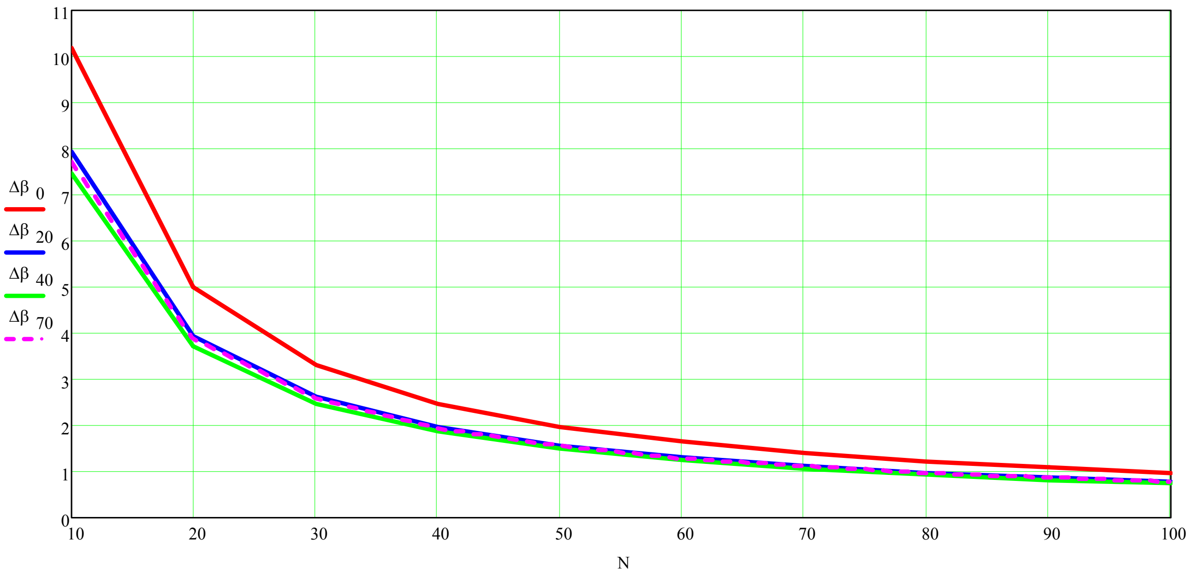

Fig. 5. The relationship between the angular selectivity and the number of periods in the grating

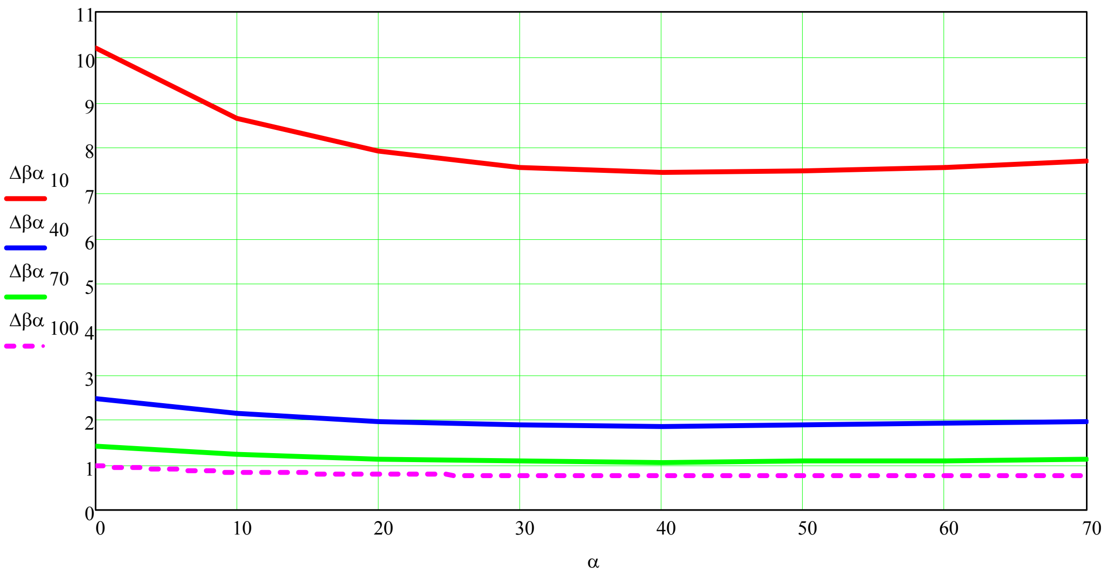

Fig. 6. The relationship between the angular selectivity and the incident radiation angle

4. Conclusions

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